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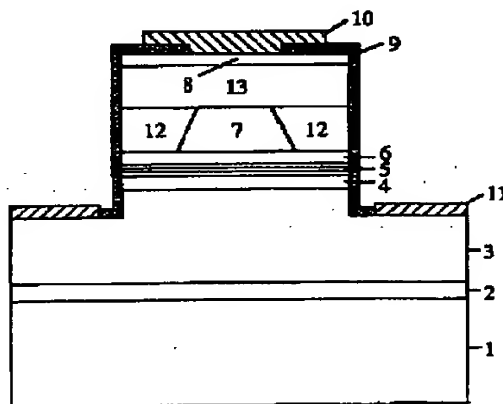
(54) **SEMICONDUCTOR LASER ELEMENT**

(57) Abstract:

PROBLEM TO BE SOLVED: To reduce the element resistance and the operation voltage of a semiconductor laser in the blue violet wavelength region.

SOLUTION: A semiconductor laser element is constituted of optical waveguide layers 3, 7, 13, light separation and confinement layers 4, 6, an active layer 5 and a contact layer 8. The layers 7, 13, 13 which are P-type crystal layers are made a superlattice heterostructure wherein all of the In composition are modulated, and P-type impurities are subjected to modulation doping by synchronizing the modulated structure of the In composition. Since the positive hole carrier concentration of a P-type optical waveguide layer can be activated nearly one figure higher than the conventional case, resistivity of the P-type optical waveguide layer can be reduced, and contact resistance between a P-type contact layer and a P-side electrode can be also improved. Therefore, the element resistance is reduced to be 1/5-1/10 of the conventional case, and the element operation voltage when the injection current is 20mA can be reduced to be 3.1-3.3V as compared with 3.6V in the conventional case.

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[Claim(s)]

[Claim 1] The above-mentioned optical waveguide field is the semiconductor-laser element characterized by to have the superstructure field formed by carrying out the laminating of two kinds of semiconductor layers from which In composition differs by turns, and to introduce p type impurity only into the semiconductor layer with large In composition in the above-mentioned superlattice field including the optical waveguide field which is joined by the active region which has a barrier layer, and this barrier-layer field, and consists of a semiconductor with larger forbidden-band width of face than this barrier layer.

[Claim 2] The optical waveguide field which is joined by the active region which has a barrier layer, and this barrier-layer field, and consists of a semiconductor with larger forbidden-band width of face than this barrier layer, The contact field in which it is joined by this optical waveguide field, and the current-supply-source means to this active region is prepared is included. The above-mentioned optical waveguide field and the above-mentioned contact field are a semiconductor laser element characterized by having the superstructure field formed by carrying out the laminating of two kinds of semiconductor layers from which In composition differs by turns, and introducing p type impurity only into the semiconductor layer with large In composition in the above-mentioned superlattice field.

[Claim 3] Two kinds of semiconductor layers which constitute the above-mentioned superstructure field are semiconductor laser elements according to claim 1 or 2 characterized by the composition element except In being the same.

[Claim 4] The semiconductor layer into which p type impurity is not introduced among two kinds of semiconductor layers which constitute the above-mentioned superstructure field in the above-mentioned optical waveguide field is a semiconductor laser element according to claim 1 to 3 characterized by not including In as a composition element.

[Claim 5] The above-mentioned barrier layer is a semiconductor laser element according to claim 1 to 4 characterized by the bird clapper from the III-V group compound semiconductor which contains nitrogen as a composition element.

[Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] this invention is

[0002] about the semiconductor laser element suitable for an optical information terminal or the optical application measurement light source. :

[Description of the Prior Art] About the light emitting device of a blue field, the element structure which constitutes blue light emitting diode is described in an applied physics letter magazine and 1994 in 64 volumes and 1687 - 1689 pages (Appl.Phys.Lett., 64, 1687-1689(1994).), and the example of production of the lightguide using GaInN/GaN/AlGaIn material or a luminescence barrier layer is shown until now.

[0003]

[Problem(s) to be Solved by the Invention] Although the conventional technology which the above-mentioned paper magazine indicates has described the luminescence barrier layer and the whole lightguide composition in the blue light emitting diode which used nitride system material, in this kind of element, the level of p type carrier concentration of a lightguide is still low, and neither element resistance nor operating voltage is improved enough. Moreover, about the technique of raising p type carrier concentration, a detail is not explained and reference is not made to the content about the structure of reducing the element resistance and operating voltage in semiconductor laser with stripe geometry further. For example, in the compound semiconductor laser which consists of a III-V group element, p type lightguide and p type contact layer are prepared between a barrier layer and p lateral electrode. These layers inject II group element (for example, Mg) into the compound semiconductor layer of a III-V group element as a dopant, and are formed. The dopant of II group element replaces and goes into an III group element to the site to which an III group element exists in the crystal of a compound semiconductor. Since there are few a peripheral electrons compared with an III group element, if II group element with few one peripheral electron goes into this site, it will serve as a cation, namely, will offer an electron hole. This electron hole serves as a carrier in a p type semiconductor, and the amount determines the element resistance and operating voltage in a semiconductor laser element. By the way, begin above-mentioned blue light emitting diode, and it sets to light emitting devices, such as a semiconductor laser element. The dopant ion

concentration in above-mentioned p type lightguide in obtaining the element resistance and operating voltage which are sufficient for practical use. Although it is requested that (namely, II group element concentration which went into the site of an III group element and was ionized) should be carried out more than $5 \times 10^{18} \text{cm}^{-3}$ – $1 \times 10^{19} \text{cm}^{-3}$ or this about $5 \times 10^{17} \text{cm}^{-3}$ – $1 \times 10^{18} \text{cm}^{-3}$ or more than this, and p type contact layer. This concentration was actually saturated with $5 \times 10^{16} \text{cm}^{-3}$ – $1 \times 10^{17} \text{cm}^{-3}$ to the injection rate of a dopant in the GaN layer, therefore carrier concentration of p type lightguide or p type contact layer was not able to be raised enough.

[0004] Especially, with III-V group nitride system compound semiconductor material, the main purposes of this invention realize resistivity reduction of difficult p type lightguide, and attain the reduction in resistance of a laser element and the reduction in operating voltage which consist of the compound semiconductor concerned. Moreover, the refractive index of p type lightguide is raised desirably, the large waveguide structure of an optical locked-in effect is formed near the barrier layer of a semiconductor laser element, and luminous efficiency is raised. attaining these purposes -- especially, laser operation (laser beam oscillation) of the purple-blue color wavelength field in the device which consists of nitride system compound semiconductor material -- a low threshold -- and it can realize by low resistance low operating voltage, and reliability is raised over a long period of time.

[0005]

[Means for Solving the Problem] In order to improve especially the level of the carrier concentration in the p type semiconductor layer whose bulk growth of a nitride system semiconductor was inadequate in attaining the above-mentioned purpose in production of the semiconductor laser which consists of a compound semiconductor first in this invention. The crystal layer (semiconductor layer) which introduced suitable In element for activation of p type carrier is prepared as a lightguide which is joined to a barrier layer or is prepared in this through other semiconductor layers (barrier layer etc.). The superlattice hetero structure which modulated In composition by atomic-layer order in this crystal layer, and was synchronized with this, and carried out the modulation dope of the p type impurity is formed. Namely, the optical waveguide field which is joined by the active

region which has a barrier layer, and the barrier-layer field concerned in this invention, and consists of a semiconductor with larger forbidden-band width of face than this barrier layer is included. It has the superstructure field formed by an optical waveguide field carrying out the laminating of two kinds of semiconductor layers from which In composition differs by turns, and the semiconductor laser element equipped with p type impurity being introduced only into the semiconductor layer with large In composition in the superlattice field as fundamental requirements for composition is produced. Moreover, you may form the superstructure field where the laminating of two kinds of semiconductor layers from which In composition differs was carried out to this contact field by turns, and it was formed in it including the contact field where it is further joined to this fundamental requirement for composition by the optical waveguide field, and the current-supply-source means to an active region is prepared in it, and p type impurity was introduced only into the semiconductor layer with large In composition of them. This semiconductor laser element is formed as what has the so-called double junction structure which usually sandwiched the small luminescence barrier layer of the forbidden-band width of face prepared in the semiconductor substrate upper part of a single crystal by the lightguide with big forbidden-band width of face. p type carrier concentration of the high layer of In composition ratio in an above-mentioned superlattice field is the range of three or less $10^{19}/\text{cm}^3$, and it is desirable to set up so that it may be activated on level with the electron hole carrier concentration higher than the case where p type impurity is doped uniformly in the lightguide concerned. In any case, you may form the direction where it is good also as the same (for example, GaPN and GaInPN), and p type impurity is not introduced among these semiconductor layers in the composition element excluding [two kinds of semiconductor layers which constitute these superstructure fields] In so that In may not be included as a composition element. Furthermore, a barrier layer may be constituted from a III-V group compound semiconductor which contains nitrogen as a composition element, and may form the so-called multiplex quantum well structure where such a two or more layers barrier layer was prepared in the above-mentioned active region.

[0006] If the outline of the semiconductor laser element composition of this

invention stated above is put in another way by the example, in the semiconductor laser element which consists of the conventional III-V group compound semiconductor, the place transposed to the superstructure which an AlGaIn lightguide becomes from an AlGaInN layer at the superstructure which a GaIn lightguide becomes from a GaInN layer, respectively will serve as the 1st feature. Moreover, it considers as the superlattice hetero structure which carried out the laminating of a GaInN layer with small In composition of p type contact layer in contact with p lateral electrode, and the GaInN layer with big In composition by turns, and the place which introduces p type impurity into a GaInN layer with big In composition serves as the 2nd feature. That is, the lightguide by which a laminating is carried out to the method of p lateral electrode of a semiconductor laser element in this invention () Or two kinds of semiconductor layers from which In composition differs in formation of a clad layer and a contact layer (one side) Prepare the superstructure field which consists of In not being included, it is made to synchronize with thin film growth of the atomic-layer order of the semiconductor layer (layer into which In was introduced to the layer which does not contain In) which enlarged In composition of this field, and the technique of carrying out the modulation dope of the p type impurity is used for this. It introduces into p type impurity by the molecular beam epitaxy (MBE) method or the organic-metal vapor-growth (MOVPE) method, using Mg or Zn as a simple substance or a raw material of an organometallic compound. When it constitutes a lightguide from a GaN layer or an AlGaIn layer, and a compound semiconductor layer that introduced In into this, it is good to perform p type impurity dope so that average p type carrier concentration in p type lightguide whole region may go into the range of 5×10^{17} to 5×10^{18} /cm³. Moreover, it is good to perform p type impurity dope in p type contact layer which consists of two kinds of GaInN layers from which In composition differs so that average p type carrier concentration in the contact layer whole region concerned may go into the range of 5×10^{18} to 2×10^{19} /cm³. Desirably, all of the lightguide and contact layer of the method of p lateral electrode are formed by the superstructure by this technique. In this invention, without changing the substantial forbidden-band width of face of a lightguide a lot, a high-concentration electron hole carrier is obtained and increase of the refractive

index accompanying introduction of In composition can be utilized for eye
 ***** in a luminescence barrier layer. By these, it operates by the low
 threshold current and the element which reduced element resistance and
 operating voltage is realized.

[0007] Furthermore, it is good to constitute so that a compressive strain or
 an optically-biaxial lattice strain may join p type lightguide by introduction
 of the oak which specifies the desirable additional requirements for
 composition for the laser element of this invention, and In composition in the
 1st, and to hold down each thickness of the In introduction layer concerned
 to under critical thickness in p type lightguide whole region. The
 semiconductor substrate of the single crystal used as the base for
 constituting a laser element in the 2nd is desirable to formation of the laser
 element which becomes being the silicon carbide (α -SiC) which has the
 sapphire (α -aluminum $2O_3$) substrate which has the Cth (0001) page
 with the Wurtzite structure of hexagonal system, or (0001) the Cth page from
 a nitride system compound semiconductor especially. In this case, in case
 optical-waveguide structure is established on a hexagonal system Wurtzite
 structure substrate, it is good to be parallel to the Ath (11-20) page of a
 substrate, or to set up the direction which forms a waveguide in the direction
 which becomes perpendicular. Moreover, you may constitute an optical
 waveguide in the embedding type (BH) stripe geometry which establishes a
 real refractive-index difference to the longitudinal direction of a
 luminescence barrier layer as stripe geometry with the rectangle-like cross-
 section configuration and by which the basic transverse mode is guided
 stably. As for the crystal layer which constitutes rectangle-like optical-
 waveguide structure, it is good to form BH stripe geometry with an insulator
 layer mask and selective-growth technology. the deformation amount child
 well layer which introduced the lattice strain constituted the luminescence
 barrier layer to extend [as the 3rd, even if it constitutes the luminescence
 barrier layer in the active region of semiconductor laser from a single
 quantum well layer, it is good also as multiplex quantum well structure
 which consists of two or more quantum wells, and] the flexibility of the
 material selection of a luminescence barrier layer and the barrier layer
 which confines an electron or an electron hole (carrier) in this -- it is good
 also as single or multiplex deformation amount child well structure

[0008] The basis of an operation characteristic of above-mentioned element composition is explained below.

[0009] In order to activate a high level conventionally and to set up the electron hole carrier concentration of p type lightguide, the technique of synchronizing with the modulated structure of the above-mentioned In composition, and introducing p type impurity is applied. In element acts in the direction which makes small forbidden-band width of face of the semiconductor to every semiconductor material. Since forbidden-band width of face is made small and the interval of a valence band and impurity level is especially narrowed relatively also to a nitride semiconductor material, carrier activation of p type impurity will be promoted. For example, since the same p type impure amount of resources can also improve the rate of activation by considering as a GaInN crystal layer to a GaN crystal layer, high electron hole carrier concentration can be set up. Therefore, according to this invention, in the lightguide of a semiconductor laser element, the electron hole carrier concentration to $10^{19}/\text{cm}^3$ can be set up arbitrarily.

[0010] Explanation of model invention is further continued using a reductio ad absurdum. For example, if In composition is introduced into the lightguide, this forbidden-band width of face will become small, and when the forbidden-band width of face of a luminescence barrier layer is approached, waveguide light will receive absorption. By this invention, absorption by the lightguide of the light which emitted light from the barrier layer and which should guide waves is prevented to this problem as superlattice hetero structure where In composition was modulated by atomic-layer order. That is, in p type lightguide, it is made to synchronize with modulating In composition by atomic-layer order, and p type impurity is introduced, and in order not to decrease forbidden-band width of face greatly, it is considering as superlattice hetero structure. Incidentally with the semiconductor layer of atomic-layer order, it is specifically specified as a number atomic-layer thick part and the thing which has the thickness around 10Å on the basis of the size of 5.166Å of one atom which constitutes this (diameter) (since the laminating of the atom is carried out to the shape of a hound's-tooth check). Moreover, although p type contact layer in contact with p lateral electrode is made into the superstructure which consists of two sorts of p type GaInN layers from which In composition ratio differs, by

modulating In composition still more greatly, introducing a compressive strain into this (enlarging the difference of In composition ratio of a high In concentration layer and a low In concentration layer) superstructure, and bending the band structure of a valence band, electron hole carrier concentration is activated more and high conductivity is attained. It has been small improved by the contact resistance of p lateral electrode by this invention, and p type contact layer even in one to 5×10^{-6} -ohmcm².

[0011] Moreover, since the electron hole carrier concentration of p type lightguide becomes high by this invention, the pseudo-Fermi level is set up more highly and the energy barrier of p type lightguide to a luminescence barrier layer can be set up greatly. For this reason, since the overflow carrier (electron which goes into p type lightguide from a barrier layer, without contributing to luminescence) from a barrier layer was suppressed, it was possible to have improved eye carrier ***** in a barrier layer. To the element property, the effect of low threshold operation or the operational stability under an elevated temperature was also seen.

[0012] Establishing the superlattice hetero structure which modulated In composition near the barrier layer leads to the ability of the ***** coefficient in a barrier layer to be designed greatly compared with the lightguide which does not introduce In composition. This is because the refractive index of the crystal layer which introduced In composition can be enlarged, and the size of In composition and the thing which introduced and for which eye ***** of a barrier layer is designed and adjusted by the thickness of a thin film layer or the total thickness of a superstructure are repeatedly possible for it. By carrying out optimal design of this ***** coefficient, low threshold efficient operation and elevated-temperature operation can be obtained, and the aspect ratio of a far field pattern can be adjusted.

[0013] It was possible to have reduced the operating voltage at the time of the reduction in resistance and laser oscillation of an element by the above. Moreover, the low threshold of an element and efficient operation were attained by applying the refractive-index waveguide stripe geometry which can attain stabilization of the basic transverse mode.

[0014]

[Embodiments of the Invention] Hereafter, the form of operation of this

invention described in an example 1 or 5, and these related drawings explains this invention in detail.

[0015] One example of a <example 1> this invention is explained to be drawing 1 (a) by (b). On the sapphire (alpha-aluminum $2O_3$) substrate 1 which has the Cth (0001) page of drawing 1 (a) first After heat-treating a substrate in 1200 degrees C from the temperature of 1000 degrees C, supplying ammonia NH_3 by the organic-metal vapor growth, In the temperature of 450-550 degrees C, grow up and the GaN buffer layer 2 is set in temperature of 1000-1100 degrees C. The n type GaN lightguide 3, the n type AlGaInN lightguide 4, An undoping GaN quantum barrier layer And the compressive-strain multiplex quantum well barrier layer 5 which consists of an undoping GaInN quantum well layer, the p type AlGaInN superlattice hetero structure lightguide 6, the p type GaN/GaInN superlattice hetero structure lightguide 7, and the p type GaInN/GaInN superlattice hetero structure contact layer 8 It prepares. Under the present circumstances, p type lightguide 6, p type lightguide 7, and p type contact layer 8 were made into the superlattice hetero structure where In composition was modulated altogether, as typically shown in drawing 1 (b), they formed the lightguide and the contact layer by the repeat of the superlattice thin film layer of atomic-layer order, and Mg of p type impurity is synchronized with the modulated structure of In composition, and they have introduced it. Therefore, Mg is doped by the AlGaInN layer of a lightguide 6, the GaInN layer of a lightguide 7, and the GaInN layer (direction of In composition size) of the contact layer 8, and nothing is doped by the AlGaInN layer of a lightguide 6, the GaN layer of a lightguide 7, and the GaInN layer (direction of In composition smallness) of the contact layer 8. In the form of an organometallic compound, p type impurity Mg is the range of 5×10^{17} to 2×10^{18} /cm³, and was introduced into p type contact layer 8 at p type lightguide 6 and p type lightguide 7, respectively in the range of 5×10^{18} to 2×10^{19} /cm³. Next, by photo lithography and etching processing, as shown in drawing 1 (a), a part of crystal layer is removed until it results in a layer 3. Then, an insulator layer 9 is formed and the direction of a window region stripe is formed in the direction parallel to the Ath page in this 2Oalpha-aluminum 3 substrate 1 (11-20). Moreover, the vacuum evaporation of the pattern of the p lateral electrode 10 and the n lateral electrode 11 is carried

out with lithography. Finally, the element cross section shown in drawing 1 (a) is obtained by carrying out the cleavage of the substrate in the perpendicular direction to an optical-waveguide stripe.

[0016] According to this example, since the electron hole carrier concentration of p type GaN and an AlGaIn lightguide was more highly [than before / about 1 figure] activable, the resistivity of p type lightguide has been reduced. Furthermore, the contact resistance of p type contact layer and p lateral electrode can also be small improved even in one to 5×10^{-6} -ohmcm². Thereby, element resistance of this example could be reduced from 1/5 of the conventional element to 1/10 (it is dependent on In composition ratio of each class), and has reduced o'clock of 20mA element operating voltage of inrush currents even to 3.1-3.3V to conventional 3.6V further. Moreover, since electron hole carrier concentration can be made high by this invention, the pseudo-Fermi level of p type lightguide can be made higher. Thereby, the energy barrier of p type lightguide to a luminescence barrier layer was able to be enlarged. As for this, it was possible to have suppressed the overflow carrier from a barrier layer, and for the carrier in a barrier layer to have closed, and to have made eye ** improve. Furthermore, since In is contained in p type lightguide, the refractive index becomes high and enlarges the ***** coefficient near the luminescence barrier layer. This element structure had gain waveguide type stripe geometry, and in a room temperature, laser operation is possible for it, and it obtained the element which carries out laser oscillation in the range which is 410-430nm of a purple-blue color wavelength region.

[0017] Drawing 2 explains other examples of a <example 2> this invention. After forming in a p type GaN/GaInN superlattice to the terrorism assembling-die lightguide 7, the insulator layer mask extended in the shape of a stripe in the upper surface center section of the lightguide 7 by photo lithography is formed, further, although an element is produced like an example 1, a lightguide 7 is removed and a ridge stripe is formed by etching using this insulator layer mask, until the upper surface of the p type AlGaIn/AlGaInN superlattice heterojunction type lightguide 6 is exposed. Next, the selective growth of the n type GaN current constriction layer 12 is carried out using an insulator layer mask. After removing an insulator layer mask, the p type GaN/GaInN superlattice hetero structure embedding layer

13 and the p type GaInN/GaInN superlattice hetero structure contact layer 8 are formed. Next, by photo lithography and etching processing, as shown in drawing 2, the both sides of ridge stripe geometry are removed until it results in a layer 3. Then, an element is produced completely like an example 1.

[0018] Since it was made to the refractive-index waveguide structure where the current constriction layer 12 was formed according to this example, the element of a low threshold was obtained rather than the example 1. The threshold current has been reduced even from 1/3 to 1/5 compared with the example 1. The range of a purple-blue color wavelength region of oscillation wavelength was 410-430nm.

[0019] Drawing 3 explains other examples of a <example 3> this invention. First, it prepares to the n type GaN lightguide 3 like an example 1 or 2. Next, the insulator layer mask 14 for selective growths of two articles extended in the shape of a stripe is formed in the lightguide 3 upper surface by photo lithography and etching. Then, the selective growth of the compressive-strain multiplex quantum well barrier layer 5 which becomes a start from the n type AlGaIn lightguide 4, an undoping GaN quantum barrier layer, and an undoping GaInN quantum well layer about the regrowth of the n type GaN lightguide 3, the p type AlGaIn/AlGaInN superlattice hetero structure lightguide 6, the p type GaN/GaInN superlattice hetero structure lightguide 7, and the p type GaInN/GaInN superlattice hetero structure contact layer 8 is carried out by the organic-metal vapor growth. That is, at the process from the regrowth of a lightguide 3, since the crystal growth has arisen alternatively in the field divided with the stripe-like insulator layer mask of two articles, the layered product of the crystal which has a rectangle cross section as shown in drawing 3 is formed. Then, an insulator layer 9 is formed and vacuum evaporation formation of the pattern of the p lateral electrode 10 and the n lateral electrode 11 is carried out with lithography. Furthermore, the element cross section shown in drawing 3 is obtained by carrying out the cleavage of the substrate in the direction perpendicular to a waveguide.

[0020] According to this example, BH stripe geometry which guides the basic transverse mode stably according to a real refractive-index difference was producible. With this element, rather than the element of an example 1,

since the large refractive-index difference of a barrier-layer longitudinal direction can be taken, waveguide light can be spread stably. Furthermore, since the current constriction effect was also large, low threshold operation was possible. The threshold current has been reduced even from $1/2$ to $1/3$ to the pan compared with the example 2. The range of a purple-blue color wavelength region of oscillation wavelength was 410-430nm.

[0021] Drawing 4 explains other examples of a <example 4> this invention. Although an element is produced like an example 3, the selective growth of the same crystal layer as an example 3 is carried out using the insulator layer mask 14 containing a dummy pattern as shown in the outside of BH stripe geometry equivalent to an example 3 at drawing 4. A dummy pattern is a selective-growth field (field divided with the insulator layer mask) which prepares one articles of insulating stripe-like masks at a time in abbreviation parallel, and is formed in these on the outside of the insulating mask of the shape of a stripe of two articles established by element formation of drawing 3 and which was newly formed when putting in another way. To the stripe on a dummy pattern, the insulator layer mask 9 is carried out like drawing 4, is covered, and it is made not to pour in current. Then, the element cross section shown in drawing 4 is obtained by carrying out the vacuum evaporation of the electrode, and carrying out the cleavage of the substrate.

[0022] According to this example, the crystallinity of the waveguide crystal layer in BH stripe geometry of a center section is improvable with the dummy pattern. Consequently, compared with an example 3, low threshold operation is possible, and the threshold current has been reduced from the example 3 from $2/3$ to $1/2$ to the pan. Also about quantum efficiency, it has increased 50% from 30% from the example 3. The range of a purple-blue color wavelength region of oscillation wavelength was 410-430nm.

[0023] Other examples of a <example 5> this invention are explained. In this example, in the semiconductor laser element which has the element composition of already explained drawing 1 or either of 4, an n type GaN buffer layer is prepared on it at a substrate 1 using the n type silicon carbide (α -SiC) it is the Wurtzite structure of hexagonal system and the number of substrate side directions is [silicon carbide] C (0001), and an element is produced according to a publication of an example 1 or either of 4.

[0024] According to this example, since a substrate had n type conductivity, the vacuum evaporation of the electrode by the side of n was able to be carried out to the substrate rear face, and it was able to conduct current to the substrate vertical side. Since mounting which turned the joint down at the time of the assembly of a chip type element was attained by this, heat leakage nature has been improved. In this example, the laser element which operates at temperature higher than the above-mentioned example was obtained.

[0025]

[Effect of the Invention] Especially in this invention, in the III-V group nitride semiconductor material, since the electron hole carrier concentration of p type lightguide can be set now as arbitration to $10^{19}/\text{cm}^3$ and the carrier was activated highly about 1 figure rather than before, the resistivity of p type lightguide has been reduced. Furthermore, the contact resistance of p type contact layer and p lateral electrode was reduced, and it has improved small even in one to $5 \times 10^{-6} \text{-ohmcm}^2$. With the element of this invention, while reducing the resistance from 1/5 to 1/10 conventionally, o'clock of 20mA element operating voltage of inrush currents has been conventionally reduced even to 3.1-3.3V to having been 3.6V. Moreover, with high electron hole carrier concentration, since the pseudo-Fermi level in p type lightguide was made higher, the energy barrier of p type lightguide to a barrier layer has been set up more greatly than the conventional technology. a carrier [in / a barrier layer / in this] -- it was effective in shutting up Furthermore, since In composition which makes a refractive index high was incorporated by p type lightguide, to it, the ***** coefficient near the luminescence barrier layer has been designed greatly. According to these effects, with the element of this invention, it is low element resistance, and was able to operate by low operating voltage, and low threshold operation was able to be aimed at. By this invention, laser operation which consists of AlGaInN material was checked in the room temperature, and the element which carries out laser oscillation in the wavelength field of a purple-blue color in the range with an oscillation wavelength of 410-430nm was obtained.

[0026] Although this invention explained the AlGaInN semiconductor laser element produced on the sapphire of Wurtzite structure with the Cth (0001) page, or the silicon-carbide single crystal substrate, it cannot be

overemphasized that it is applicable to the semiconductor laser element using AlInGaAs/GaAs, AlGaInP/GaAs, GaInAsP/GaInAs/InP, AlInAs/GaInAs/InP, etc. which are other semiconductor-material systems.

[Brief Description of the Drawings]

[Drawing 1] It is drawing for explaining the example 1 of this invention, and (a) is element structure drawing of longitudinal section, and (b) is a superstructure p type impurity modulation dope crystal layer.

[Drawing 2] It is element structure drawing of longitudinal section showing the example 2 of this invention.

[Drawing 3] It is element structure drawing of longitudinal section showing the example 3 of this invention.

[Drawing 4] It is element structure drawing of longitudinal section showing the example 4 of this invention.

[Description of Notations]

The 1--(0001) Cth page sapphire single crystal substrate, 2 -- GaN buffer layer, 3 [-- GaInN/GaN compressive-strain multiplex quantum well structure barrier layer,] -- An n type GaN lightguide, 4 -- An n type AlGaIn light separation confining layer, 5 6 -- A p type AlGaIn light separation confining layer, 7 -- Superlattice hetero structure p type impurity modulation dope GaN lightguide, 8 [-- p lateral electrode, 11 / -- n lateral electrode, 12 / -- An n type GaN current constriction layer, 13 / -- A superlattice hetero structure p type impurity modulation dope GaN embedding layer, 14 / -- Insulator layer mask for selective growths.] -- A superlattice hetero structure p type impurity modulation dope GaInN contact layer, 9 -- An insulator layer, 10

Fig. 1

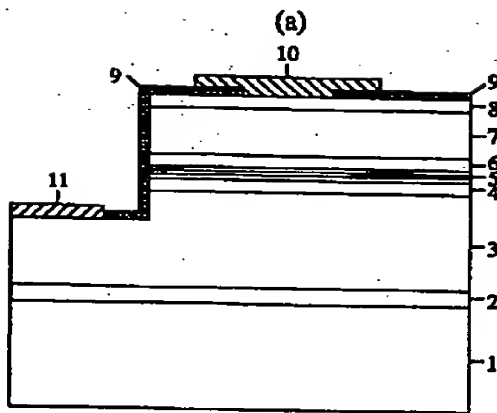
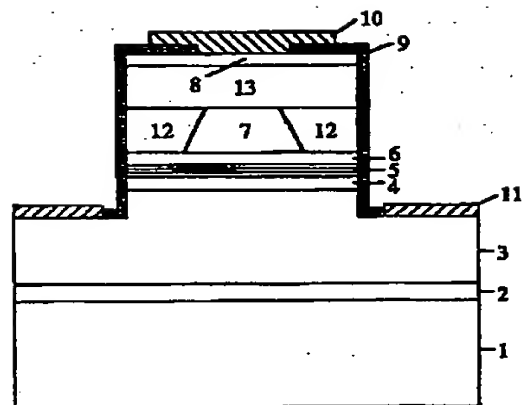


Fig. 2



(b)

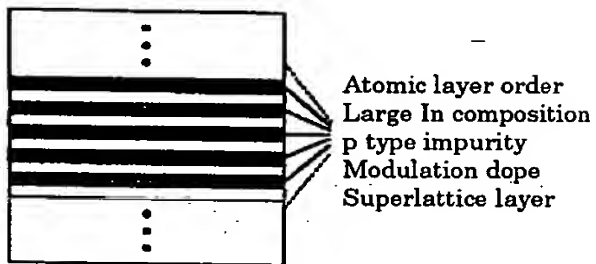


Fig. 3

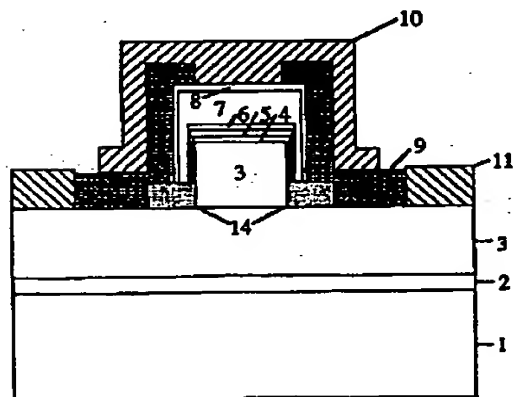
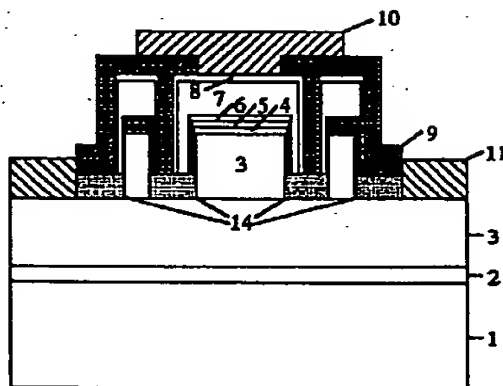


Fig. 4



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(54) 【発明の名称】 半導体レーザ素子

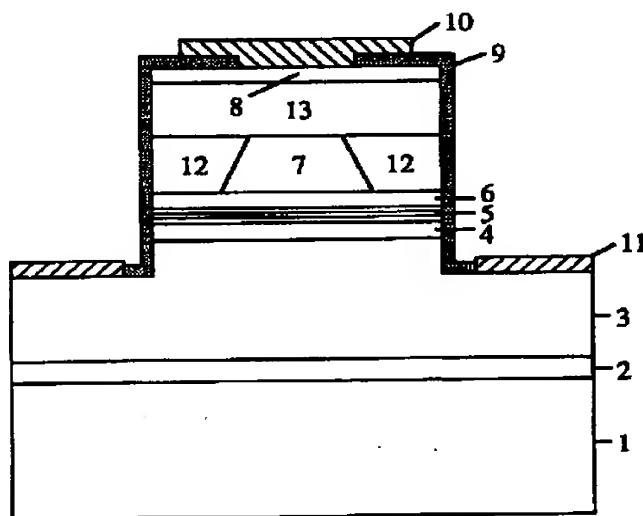
(57) 【要約】

【課題】 青紫色波長域の半導体レーザの素子抵抗や動作電圧を低減する。

【解決手段】 光導波層 3、7、13、光分離閉じ込め層 4、6、活性層 5、コンタクト層 8 からなる半導体レーザ素子において、p 型結晶層である層 7、13、13 は、すべて In 組成を変調した超格子ヘテロ構造とし、In 組成の変調構造に同期させて p 型不純物を変調ドーピングする。

【効果】 p 型光導波層の正孔キャリア濃度を従来よりも一桁近く高く活性化できたので、p 型光導波層の抵抗率を低減でき、p 型コンタクト層と p 側電極の接触抵抗も改善できた。これにより、素子抵抗を従来の 1/5 から 1/10 に低減するとともに、注入電流 20 mA 時の素子動作電圧を従来の 3.6 V に対して 3.1 ~ 3.3 V にまで低減できた。

図 2



【特許請求の範囲】

【請求項1】活性層を有する活性領域と、該活性層領域に接合され且つ該活性層より禁制帯幅の大きい半導体からなる光導波領域とを含み、上記光導波領域はIn組成の異なる2種類の半導体層を交互に積層して形成された超格子構造領域を有し、上記超格子領域においてIn組成の大きい半導体層のみにp型不純物が導入されていることを特徴とする半導体レーザ素子。

【請求項2】活性層を有する活性領域と、該活性層領域に接合され且つ該活性層より禁制帯幅の大きい半導体からなる光導波領域と、該光導波領域に接合され且つ該活性領域への電流供給手段が設けられるコンタクト領域を含み、上記光導波領域及び上記コンタクト領域はIn組成の異なる2種類の半導体層を交互に積層して形成された超格子構造領域を有し、上記超格子領域においてIn組成の大きい半導体層のみにp型不純物が導入されていることを特徴とする半導体レーザ素子。

【請求項3】上記超格子構造領域を構成する2種類の半導体層は、Inを除く構成元素が同一であることを特徴とする請求項1又は2に記載の半導体レーザ素子。

【請求項4】上記光導波領域における上記超格子構造領域を構成する2種類の半導体層のうち、p型不純物が導入されない半導体層はInを構成元素として含まないことを特徴とする請求項1乃至3のいずれかに記載の半導体レーザ素子。

【請求項5】上記活性層は、構成元素として窒素を含むIII-V族化合物半導体からなることを特徴とする請求項1乃至4のいずれかに記載の半導体レーザ素子。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、光情報端末或は光応用計測光源に適する半導体レーザ素子に関する

【0002】。

【従来の技術】これまで青色領域の発光素子に関して、青色発光ダイオードを構成する素子構造がアブライド・フィジックス・レータ誌、1994年、64巻、1687-1689頁(Appl. Phys. Lett., 64, 1687-1689(1994).)において述べられており、GaInN/GaN/AlGaIn材料を用いた光導波層や発光活性層の作製例が示されている。

【0003】

【発明が解決しようとする課題】上記論文誌が開示する従来技術では、窒化物系材料を用いた青色発光ダイオードにおける発光活性層や光導波層の全体構成について述べているが、この種の素子においては、まだ光導波層のp型キャリア濃度のレベルが低く、素子抵抗や動作電圧が十分改善されていない。また、p型キャリア濃度を向上させる手法については詳細を説明しておらず、さらにストライプ構造を有した半導体レーザにおける素子抵抗及び動作電圧を低減する構造に関した内容に対して言及していない。例えば、III-V族元素からなる化合物

半導体レーザにおいて、活性層とp側電極との間にp型光導波層とp型コンタクト層を設ける。これらの層は、III-V族元素の化合物半導体層にII族元素(例えば、Mg)をドーパントとして注入して形成される。II族元素のドーパントは、化合物半導体の結晶においてIII族元素が存在するサイトにIII族元素に替わって入る。最外殻電子が1つ少ないII族元素は、III族元素に比べて最外殻電子が1つ少ないため、このサイトに入ると正イオンとなり、即ち正孔を提供する。この正孔はp型半導体においてキャリアとなり、その量は半導体レーザ素子における素子抵抗や動作電圧を決める。ところで、上述の青色発光ダイオードをはじめ、半導体レーザ素子等の発光素子においては、実用に足る素子抵抗と動作電圧を得るにあたり、上述のp型光導波層におけるドーパントイオン濃度(即ち、III族元素のサイトに入ってイオン化したII族元素濃度)を $5 \times 10^{17} \text{cm}^{-3} \sim 1 \times 10^{18} \text{cm}^{-3}$ 又はこれ以上、p型コンタクト層については $5 \times 10^{18} \text{cm}^{-3} \sim 1 \times 10^{19} \text{cm}^{-3}$ 又はこれ以上にすることが要請されているが、現実にはGaN層にドーパントの注入量に対し、この濃度は $5 \times 10^{16} \text{cm}^{-3} \sim 1 \times 10^{17} \text{cm}^{-3}$ で飽和し、従ってp型光導波層やp型コンタクト層のキャリア濃度を充分高めることはできなかった。

【0004】本発明の主要な目的は、特にIII-V族窒化物系化合物半導体材料では困難であったp型光導波層の抵抗率低減を実現し、当該化合物半導体からなるレーザ素子の低抵抗化と低動作電圧化を図るものである。また、望ましくはp型光導波層の屈折率を高めて、半導体レーザ素子の活性層近傍に光閉じ込め効果の大きい導波構造を形成して発光効率を高める。これらの目的を達成することにより、特に窒化物系化合物半導体材料からなるデバイスにおける青紫色波長領域のレーザ動作(レーザ光発振)を低閾値でかつ低抵抗低動作電圧で実現でき、また長期信頼性を高める。

【0005】

【課題を解決するための手段】上記目的を達成するにあたり、本発明ではまず化合物半導体からなる半導体レーザの作製において、特に窒化物系半導体のバルク成長では不十分であったp型半導体層におけるキャリア濃度のレベルを改善するために、p型キャリアの活性化に好適なIn元素を導入した結晶層(半導体層)を活性層に接合され又はこれに他の半導体層(障壁層等)を介して設けられる光導波層として設け、この結晶層において原子層オーダーでIn組成を変調し且つこれに同期させてp型不純物を変調ドーブした超格子ヘテロ構造を形成する。即ち、本発明では、活性層を有する活性領域と、当該活性層領域に接合され且つこの活性層より禁制帯幅の大きい半導体からなる光導波領域とを含み、光導波領域はIn組成の異なる2種類の半導体層を交互に積層して形成された超格子構造領域を有し、その超格子領域においてIn組成の大きい半導体層のみにp型不純物が導入されている

ことを基本的な構成要件として備えた半導体レーザ素子を作製する。また、この基本的な構成要件に、さらに光導波領域に接合され且つ活性領域への電流供給手段が設けられるコンタクト領域を含め、このコンタクト領域にIn組成の異なる2種類の半導体層を交互に積層して形成され且つそのうちのIn組成の大きい半導体層のみにp型不純物が導入された超格子構造領域を形成しても良い。この半導体レーザ素子は、通常、単結晶の半導体基板上部に設けられた禁制帯幅の小さな発光活性層を禁制帯幅の大きな光導波層で挟んだ所謂二重接合構造を有するものとして形成される。上述の超格子領域におけるIn組成の高い層のp型キャリア濃度は、 $10^{19}/\text{cm}^3$ 以下の範囲で且つp型不純物を一様にドーブした場合よりも当該光導波層における正孔キャリア濃度が高いレベルに活性化するように設定することが望ましい。いずれの場合も、これらの超格子構造領域を構成する2種類の半導体層は、Inを除く構成元素を同一（例えばGaPとGaInP）としてもよく、またこれらの半導体層のうち、p型不純物が導入されない方はInを構成元素として含まないように形成しても良い。さらに活性層は、構成元素として窒素を含むIII-V族化合物半導体で構成し、このような活性層を上述の活性領域に複数層設けた所謂多重量子井戸構造を形成しても良い。

【0006】以上に述べた本発明の半導体レーザ素子構成の概要を具体例で言い替えれば、従来のIII-V族化合物半導体からなる半導体レーザ素子において、GaIn光導波層はGaIn/GaN層からなる超格子構造に、AlGaIn光導波層はAlGaIn/AlGaIn層からなる超格子構造にそれぞれ置き換えるところが第1の特徴となる。また、p側電極と接触するp型コンタクト層を、In組成の小さなGaIn層とIn組成の大きなGaIn層を交互に積層した超格子ヘテロ構造とし、In組成の大きなGaIn層にはp型不純物を導入するところが第2の特徴となる。つまり、本発明では半導体レーザ素子のp側電極方に積層される光導波層（又は、クラッド層）とコンタクト層の形成において、In組成の異なる2種類の半導体層（一方が、Inを含まなくてもよい）からなる超格子構造領域を設け、この領域のIn組成を大きくした半導体層（Inを含まない層に対してはInが導入された層）の原子層オーダーの薄膜成長に同期させて、これにp型不純物を変調ドーブする手法を用いる。p型不純物には、例えばMg又はZnを単体又は有機金属化合物の原料として用い、分子線エピタキシー(MBE)法又は有機金属気相成長(MOVPE)法により導入する。光導波層をGaIn層又はAlGaIn層とこれにInを導入した化合物半導体層で構成する場合、p型不純物ドーブは、p型光導波層全域における平均的なp型キャリア濃度が $5 \times 10^{17} \sim 5 \times 10^{18}/\text{cm}^3$ の範囲に入るように行うとよい。また、In組成の異なる2種類のGaIn層からなるp型コンタクト層におけるp型不純物ドーブは、当該コンタクト層全域における平均的なp型キャリ

ア濃度が $5 \times 10^{18} \sim 2 \times 10^{19}/\text{cm}^3$ の範囲に入るように行うと良い。望ましくは、p側電極方の光導波層及びコンタクト層を全てこの手法による超格子構造で形成する。本発明では、光導波層の実質的な禁制帯幅を大きく変えずに、高濃度の正孔キャリアが得られ、In組成の導入に伴う屈折率の増大を発光活性層における光閉じ込めに活用できる。これらにより、低閾値電流で動作し、素子抵抗や動作電圧を低減した素子を実現する。

【0007】さらに、本発明のレーザ素子に好ましい付加的な構成要件を規定するなら、第1にIn組成の導入によりp型光導波層には圧縮歪又は二軸性格子歪が加わるように構成し、p型光導波層全域において当該In導入層の夫々の膜厚を臨界膜厚未満に抑えたと良い。第2に、レーザ素子を構成するための基体となる単結晶の半導体基板は、六方晶系のWurtzite構造を有した(0001)C面を有するサファイア($\alpha\text{-Al}_2\text{O}_3$)基板又は(0001)C面を有する炭化珪素($\alpha\text{-SiC}$)であると、特に窒化物系化合物半導体からなるレーザ素子の形成に好ましい。この場合、六方晶系Wurtzite構造基板上に光導波路構造を設ける際に、導波路を形成する方向を基板の(11-20)A面に平行であるか、或いは垂直となる方向に設定するとよい。また、光導波路は矩形状の断面形状を有したストライプ構造として、発光活性層の横方向に対して実屈折率差を設けて基本横モードが安定に導波される埋め込み型(BH)ストライプ構造に構成してもよい。矩形状の光導波路構造を構成する結晶層は絶縁膜マスクと選択成長技術により、BHストライプ構造を形成するとよい。第3として、半導体レーザの活性領域における発光活性層は単一の量子井戸層で構成しても複数の量子井戸からなる多重量子井戸構造としてもよく、発光活性層とこれに電子又は正孔(キャリア)を閉じ込める障壁層の材料選定の自由度を上げるべく、発光活性層を格子歪を導入した歪量子井戸層により構成した単一或は多重歪量子井戸構造としてもよい。

【0008】上述の素子構成に特徴的な作用の根拠について、次に説明する。

【0009】p型光導波層の正孔キャリア濃度を従来よりも高レベルに活性化させ設定するために、上記のIn組成の変調構造に同期させてp型不純物を導入する手法を適用する。In元素はどの半導体材料に対しても、その半導体の禁制帯幅を小さくする方向に作用する。特に、窒化物半導体材料に対しても、禁制帯幅を小さくし、価電子帯と不純物準位の間隔を相対的に狭くするので、p型不純物のキャリア活性化を促進することになる。例えば、GaIn結晶層に対してGaIn結晶層とすることにより、同じp型不純物量でも活性化率を向上できるので、高い正孔キャリア濃度が設定できる。従って本発明によれば、半導体レーザ素子の光導波層において $10^{19}/\text{cm}^3$ までの正孔キャリア濃度を任意に設定できる。

【0010】背理法を用い本発明の説明を更に続け

る。例えば光導波層にIn組成を導入していくと、この禁制帯幅が小さくなり、発光活性層の禁制帯幅に近づくと、導波光が吸収を受けることになる。この問題に対し、本発明では、In組成を原子層オーダで変調させた超格子ヘテロ構造として、活性層から発光した導波すべき光の光導波層による吸収を防ぐ。つまり、p型光導波層では、原子層オーダでIn組成を変調するのと同期させてp型不純物を導入し、禁制帯幅を大きく減少させないために超格子ヘテロ構造としている。因みに原子層オーダの半導体層とは、例えばこれを構成する1原子の大きさ(直径)5.166 Åを基準として、数原子層厚分、具体的には10 Å前後(原子は千鳥格子状に積層されるため)の厚さを有するものと規定される。また、p側電極と接触するp型コンタクト層はIn組成比の異なる2種のp型GaInN層からなる超格子構造とするが、In組成をさらに大きく変調させて(高In濃度層と低In濃度層のIn組成比の差を大きくして)この超格子構造に圧縮歪を導入して価電子帯のバンド構造を曲げることにより、正孔キャリア濃度をより活性化させて高い導電率を達成する。本発明によるp側電極とp型コンタクト層の接触抵抗は、 $1 \sim 5 \times 10^{-6} \Omega \text{cm}^2$ にまで小さく改善できた。

【0011】また、本発明によりp型光導波層の正孔キャリア濃度は高くなるため、その擬フェルミレベルをより高く設定して、発光活性層に対するp型光導波層のエネルギー障壁を大きく設定できる。このため、活性層からのオーバーフローキャリア(発光に寄与することなく活性層からp型光導波層へ入る電子)を抑制できるので、活性層におけるキャリア閉じ込めを改善することが可能であった。素子特性に対しては、低閾値動作や高温下での安定動作という効果も見られた。

【0012】活性層近傍にIn組成を変調した超格子ヘテロ構造を設けることは、In組成を導入しない光導波層に比べて、活性層における光閉じ込め係数を大きく設計できることにつながる。これは、In組成を導入した結晶層の屈折率を大きくできることによるもので、In組成の大きさや導入した繰り返し薄膜層の膜厚や超格子構造の総膜厚によって、活性層の光閉じ込めを設計して調節することが可能である。この光閉じ込め係数を最適設計することにより、低閾値高効率動作や高温動作を得ることができ、また遠視野像のアスペクト比を調整することができる。

【0013】以上により、素子の低抵抗化とレーザ発振時の動作電圧を低減することが可能であった。また、基本横モードの安定化を図ることができる屈折率導波ストライプ構造を適用することにより、素子の低閾値や高効率動作を達成した。

【0014】

【発明の実施の形態】以下、実施例1乃至5及びこれらの関連図面に記した本発明の実施の形態により、本発明を詳細に説明する。

【0015】<実施例1>本発明の一実施例を図1(a)と(b)により説明する。まず図1(a)の(0001)C面を有するサファイア($\alpha\text{-Al}_2\text{O}_3$)基板1上に、有機金属気相成長法によりアンモニア NH_3 を供給しながら温度1000℃から1200℃の範囲で基板を熱処理した後、温度450～550℃においてGaNバッファ層2を成長し、温度1000～1100℃においてn型GaN光導波層3、n型AlGaIn光導波層4、アンドープGaIn量子障壁層及びアンドープGaIn量子井戸層からなる圧縮歪多重量子井戸活性層5、p型AlGaIn/AlGaInN超格子ヘテロ構造光導波層6、p型GaIn/GaInN超格子ヘテロ構造光導波層7、p型GaInN/GaInN超格子ヘテロ構造コンタクト層8を設ける。この際、p型光導波層6とp型光導波層7及びp型コンタクト層8は、すべてIn組成を変調させた超格子ヘテロ構造とし、図1(b)に模式的に示すように原子層オーダの超格子薄膜層の繰り返しにより光導波層及びコンタクト層を形成し、p型不純物のMgをIn組成の変調構造に同期させて導入している。従って、光導波層6のAlGaIn層、光導波層7のGaIn層、コンタクト層8のGaIn層(In組成大の方)にはMgがドーピングされ、光導波層6のAlGaIn層、光導波層7のGaIn層、コンタクト層8のGaIn層(In組成小の方)には何もドーピングされていない。p型不純物Mgは有機金属化合物の形で、p型光導波層6とp型光導波層7に $5 \times 10^{17} \sim 2 \times 10^{18} / \text{cm}^3$ の範囲で、p型コンタクト層8に $5 \times 10^{18} \sim 2 \times 10^{19} / \text{cm}^3$ の範囲で夫々導入した。次に、フォトリソグラフィとエッチング加工により、図1(a)に示すように、結晶層の一部を層3に到るまで除去する。その後、絶縁膜9を設けて、窓領域ストライプ方向を該 $\alpha\text{-Al}_2\text{O}_3$ 基板1における(11-20)A面と平行な方向に形成する。また、リソグラフィにより、p側電極10とn側電極11のパターンを蒸着する。最後に、光導波路ストライプに対して垂直な方向に基板を劈開することによって、図1(a)に示す素子断面を得る。

【0016】本実施例によると、p型GaIn及びAlGaIn光導波層の正孔キャリア濃度を従来よりも一桁近く高く活性化できたので、p型光導波層の抵抗率を低減できた。さらに、p型コンタクト層とp側電極の接触抵抗も $1 \sim 5 \times 10^{-6} \Omega \text{cm}^2$ にまで小さく改善することが可能であった。これにより、本実施例の素子抵抗は従来の素子の1/5から1/10(各層のIn組成比に依存)に低減でき、さらに注入電流20 mA時の素子動作電圧は従来の3.6 Vに対して3.1～3.3 Vにまで低減できた。また、本発明により正孔キャリア濃度を高くできるため、p型光導波層の擬フェルミレベルをより高くできる。これにより、発光活性層に対するp型光導波層のエネルギー障壁を大きくできた。このことは、活性層からのオーバーフローキャリアを抑制し、活性層におけるキャリアの閉じ込めを改善させることが可能であった。さらに、p型光導波層にはInが含まれているので、その屈折率は高くなり、発光活性層近傍の光閉じ込め係数を大きくしている。本素

子構造は、利得導波型のストライプ構造を有しており、室温においてレーザ動作が可能であり、青紫色波長域の410～430nmの範囲でレーザ発振する素子を得た。

【0017】＜実施例2＞本発明の他の実施例を図2により説明する。実施例1と同様にして素子を作製するが、p型のGa_N/GaInN超格子ヘテロ接合型光導波層7まで形成した後、フォトリソグラフィにより光導波層7の上面中央部にストライプ状に延伸する絶縁膜マスクを形成し、更にこの絶縁膜マスクを用いたエッチングにより、p型AlGa_N/AlGaInN超格子ヘテロ接合型光導波層6の上面が露出するまで光導波層7を除去してリッジストライプを形成する。次に、絶縁膜マスクを利用して、n型Ga_N電流狭窄層12を選択成長する。絶縁膜マスクを除去した後、p型Ga_N/GaInN超格子ヘテロ構造埋め込み層13とp型GaInN/GaInN超格子ヘテロ構造コンタクト層8を設ける。次に、フォトリソグラフィとエッチング加工により、図2に示すように、リッジストライプ構造の両側を層3に到るまで除去する。その後、実施例1と全く同様にして、素子を作製する。

【0018】本実施例によると、電流狭窄層12を設けた屈折率導波構造にできているので、実施例1よりも低閾値の素子を得た。閾値電流は、実施例1に比べて、1/3から1/5にまで低減できた。発振波長は、青紫色波長域の410～430nmの範囲であった。

【0019】＜実施例3＞本発明の他の実施例を図3により説明する。まず、実施例1や2と同様にして、n型のGa_N光導波層3まで設ける。次に、フォトリソグラフィとエッチングにより、光導波層3上面にストライプ状に延伸した2条の選択成長用の絶縁膜マスク14を形成する。その後、n型Ga_N光導波層3の再成長を皮切りに、n型AlGa_N光導波層4、アンドープGa_N量子障壁層及びアンドープGaInN量子井戸層からなる圧縮歪多重量子井戸活性層5、p型AlGa_N/AlGaInN超格子ヘテロ構造光導波層6、p型Ga_N/GaInN超格子ヘテロ構造光導波層7、p型GaInN/GaInN超格子ヘテロ構造コンタクト層8を有機金属気相成長法により選択成長させる。即ち、光導波層3の再成長からの工程では、結晶成長が2条のストライプ状絶縁膜マスクで仕切られた領域で選択的に生じているため、図3に示すような矩形断面を有する結晶の積層体が形成される。その後、絶縁膜9を形成して、リソグラフィにより、p側電極10とn側電極11のパターンを蒸着形成する。さらに、導波路とは垂直な方向に基板を劈開することによって図3に示す素子断面を得る。

【0020】本実施例によると、実屈折率差によって基本横モードを安定に導波するBHストライプ構造を作製できた。本素子では、実施例1の素子よりも、活性層横方向の屈折率差が大きくとれるので、導波光を安定に伝搬できる。さらに、電流狭窄効果も大きいので、低閾値

動作が可能であった。閾値電流は、実施例2に比べて、さらに1/2から1/3にまで低減できた。発振波長は、青紫色波長域の410～430nmの範囲であった。

【0021】＜実施例4＞本発明の他の実施例を図4により説明する。実施例3と同様にして素子を作製するが、実施例3に相当するBHストライプ構造の外側に図4に示すようなダミーパターンを含む絶縁膜マスク14を利用して実施例3と同じ結晶層を選択成長する。ダミーパターンとは、図3の素子形成で設けた2条のストライプ状の絶縁膜マスクの外側に、これらに略平行に1条ずつストライプ状の絶縁膜マスクを設けて形成される、換言すれば新たに形成された選択成長領域（絶縁膜マスクで仕切られた領域）である。ダミーパターン上のストライプに対しては絶縁膜マスク9を図4のようにしてカバーして、電流を注入しないようにする。その後、電極を蒸着しかつ基板を劈開することにより、図4に示す素子断面を得る。

【0022】本実施例によると、ダミーパターンにより中央部のBHストライプ構造における導波路結晶層の結晶性を改善できた。この結果、実施例3に比べて低閾値動作が可能であり、閾値電流を実施例3よりさらに2/3から1/2に低減できた。量子効率についても、実施例3より30%から50%増大できた。発振波長は、青紫色波長域の410～430nmの範囲であった。

【0023】＜実施例5＞本発明の他の実施例を説明する。本実施例では、既に説明した図1乃至4のいずれかの素子構成を有する半導体レーザ素子において、基板1に六方晶系のWurtzite構造であり基板面方位が(0001)C面であるn型の炭化珪素(α-SiC)を用い、その上にn型Ga_Nバッファ層を設けて、実施例1乃至4のいずれかの記載に準じて素子を作製する。

【0024】本実施例によると、基板がn型の導電性を有するために、n側の電極は基板裏面に蒸着して、基板上下面に電流を通すことができた。これにより、チップ素子の組立時において、接合部を下にしたマウントが可能となるので、熱放散性を向上できた。本実施例では、上記実施例よりも、高い温度で動作するレーザ素子を得た。

【0025】

【発明の効果】本発明では、特にIII-V族窒化物半導体材料において、p型光導波層の正孔キャリア濃度を 10^{19} /cm³まで任意に設定できるようになり、従来よりも一桁近く高くキャリアを活性化できるので、p型光導波層の抵抗率を低減できた。さらに、p型コンタクト層とp側電極の接触抵抗を低減し、 $1\sim5\times10^{-6}\Omega\text{cm}^2$ にまで小さく改善できた。本発明の素子ではその抵抗を従来より1/5から1/10に低減するとともに、注入電流20mA時の素子動作電圧を従来は3.6Vであったのに対して3.1～3.3Vにまで低減できた。また、高い正孔キャリア濃度により、p型光導波層における擬フェルミレベルを

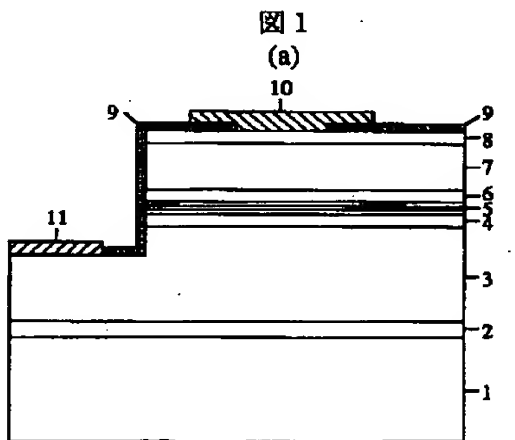
より高くできるので、活性層に対する p 型光導波層のエネルギー障壁を従来技術より大きく設定できた。これは、活性層におけるキャリアの閉じ込めに有効であった。さらに、p 型光導波層には、屈折率を高くする In 組成が取り込まれているので、発光活性層近傍の光閉じ込め係数を大きく設計できた。これらの効果によって、本発明の素子では、低素子抵抗でかつ低動作電圧で動作し、低閾値動作を図ることができた。本発明により、AlGaInN 材料からなるレーザ動作を室温において確認し、発振波長 410~430 nm の範囲で青紫色の波長領域でレーザ発振する素子を得た。

【0026】本発明では、(0001)C 面を有した Wurtzite 構造のサファイアや炭化珪素単結晶基板上に作製した AlGaInN 半導体レーザ素子について説明したが、他の半導体材料系である AlInGaAs/GaAs、AlGaInP/GaAs、GaInAsP/GaInAs/InP、AlInAs/GaInAs/InP 等を用いた半導体レーザ素子に適用できることはいうまでもない。

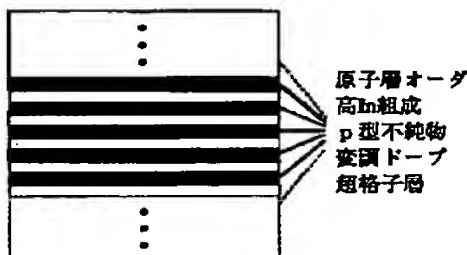
【図面の簡単な説明】

【図 1】本発明の実施例 1 を説明するための図であり、

【図 1】



(b)



(a) は素子構造縦断面図、(b) は超格子構造 p 型不純物変調ドーピング結晶層である。

【図 2】本発明の実施例 2 を示す素子構造縦断面図である。

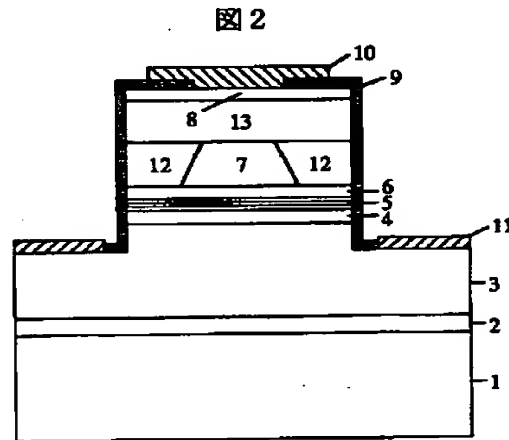
【図 3】本発明の実施例 3 を示す素子構造縦断面図である。

【図 4】本発明の実施例 4 を示す素子構造縦断面図である。

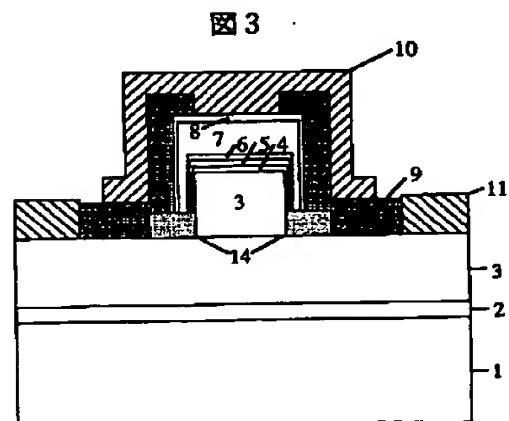
【符号の説明】

1…(0001)C 面サファイア単結晶基板、2…GaN バッファ層、3…n 型 GaN 光導波層、4…n 型 AlGaIn 光分離閉じ込め層、5…GaInN/GaN 圧縮歪多重量子井戸構造活性層、6…p 型 AlGaIn 光分離閉じ込め層、7…超格子ヘテロ構造 p 型不純物変調ドーピング GaInN 光導波層、8…超格子ヘテロ構造 p 型不純物変調ドーピング GaInN コンタクト層、9…絶縁膜、10…p 側電極、11…n 側電極、12…n 型 GaN 電流狭窄層、13…超格子ヘテロ構造 p 型不純物変調ドーピング GaN 埋め込み層、14…選択成長用絶縁膜マスク。

【図 2】

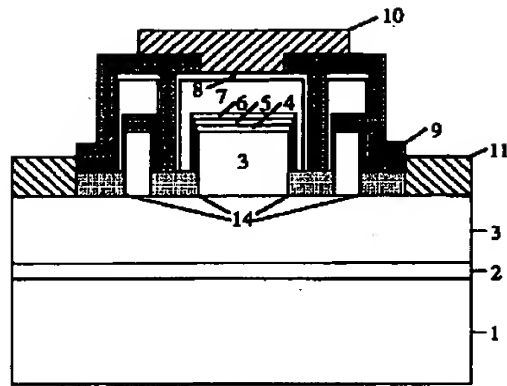


【図 3】



【図 4】

図 4



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